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Influence of Rotations under Irrigation on Potato Scab, Rhizoctonia, and Fusarium Wilt

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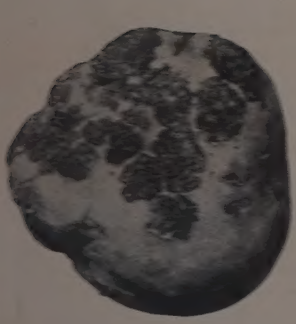
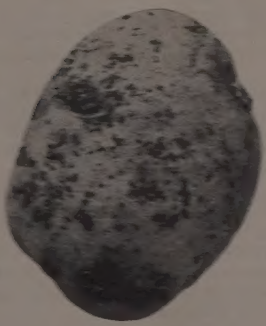
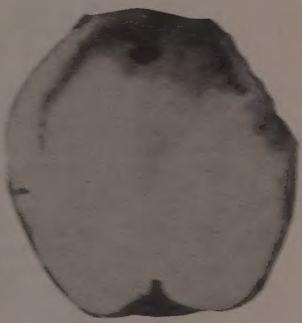


Scab



Rhizoctonia



Fusarium stem-end rot

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SUMMARY

The irrigated rotation plots at the Scottsbluff Substation were utilized for a study of the occurrence of potato scab, rhizoctonia, and fusarium wilt. These rotations were started in 1912. The disease records were made in the years 1929 to 1936.

The crops grown in the rotations in addition to potatoes are sugar beets, corn, oats, and alfalfa and in some of the rotations barnyard manure is applied. The rotations vary from one to seven years in length.

The study included the effect of (1) the length of the rotation, (2) the use of manurial treatments, (3) alfalfa as a green manure, and (4) the other crops in the rotation, especially the crop immediately preceding potatoes, upon the occurrence of these soil-borne diseases.

The data were obtained by sampling the harvested crop and examining tubers for each of the diseases. Records were also made of the development of fusarium wilt in the field during the summer.

Scab was most severe in the short rotations with sugar beets and least in the long four-to-six-year rotations in which alfalfa preceded potatoes.

Applications of barnyard manure in the short rotations increased the amount of scab. The total yield was so greatly increased, however, that more marketable tubers were produced in spite of the increase in scab.

Rhizoctonia was most severe with continuous culture of potatoes and in the short rotations, while very little occurred in the long rotations with alfalfa.

The application of barnyard manure in the short rotations decreased the percentage of tubers infected with rhizoctonia.

The highest percentage of fusarium wilt occurred in the two-year rotation with corn. Continuous potato culture and short rotations with grain resulted in more fusarium wilt than did the longer rotations with alfalfa preceding potatoes, in which the percentage of infection was very low.

On the basis of foliage symptoms, *F. solani* v. *eumartii* was responsible for the greater part of the fusarium wilt. The disease was most evident in the field during the first half of September. The percentage of tubers showing symptoms in the bin closely paralleled the percentage of infected plants in the field.

Considering both yields and disease, the best rotations are those with alfalfa preceding potatoes and with three- to six-year intervals between potato crops. If short rotations are employed the use of manure is advisable. If fusarium wilt is a problem, the use of corn preceding potatoes is inadvisable.

Influence of Crop Rotations under Irrigation on Potato Scab, Rhizoctonia, and Fusarium Wilt

R. W. GOSS AND M. M. AFANASIEV

One of the problems of maintaining high yields of marketable potatoes is that of controlling the diseases that reduce either the total yield or the quality of the crop. While many potato diseases can be controlled by the use of disease-free seed tubers, seed treatment, or sprays, these methods are not entirely effective against soil-borne diseases. Potato scab, rhizoctonia, and fusarium wilt may be caused by infection from either the seed tubers or the soil. The use of seed free of these diseases is an advisable practice, and seed treatments have proved effective in the control of scab and rhizoctonia. The results of such control methods, however, are often very disappointing if no precaution is taken against infection from the soil.

It is often recommended that three or four years should elapse between crops of potatoes on the same soil, and this has been found by experience to be desirable. Undoubtedly the continuous cropping of land to potatoes increases the microorganisms which cause these diseases and is therefore a poor practice. On the other hand, these diseases have been known to occur in a severe form when apparently healthy potatoes were planted on virgin soil or soil not previously planted to potatoes. It is obvious then that the mere lapse of three or four years between potato crops is not in itself a guarantee against disease. Other factors, such as the crops preceding potatoes or the cultural practices employed, probably influence the occurence of these diseases. In order to determine the effect of different cropping systems, a careful record was made of potato scab, rhizoctonia, and fusarium wilt in irrigated rotation plots during the years 1929 to 1936 inclusive.

DESCRIPTION OF THE PLOTS.

The plots used in this study are located at the Scotsbluff Substation [1] on the North Platte reclamation project in western Nebraska at an altitude of about 4,000 feet. During the years 1932 to 1936 the average monthly mean maximum and minimum temperatures were as follows: June 82 and 53, July 92 and 60, August 88 and 57, and September 77 and 45. The greatest divergence from these temperatures occurred in September, 1934, when the mean maximum and minimum temperatures, 72 and 41, were much lower than the average. The year 1936 was characterized by higher temperatures throughout the growing season than occurred in the other four years.

[1] The rotation experiments used in this study were planned and are conducted by the Division of Western Irrigation Agriculture of the U. S. Department of Agriculture cooperating with the University of Nebraska. The authors are greatly indebted to the late James A. Holden, former superintendent of the Substation, and to Lionel Harris, acting superintendent, for all yield data, plot histories, temperature records, and samples used in this study.

The effective rainfall [2] for the period June 15 to October 1 for the same years was as follows: 1932, 3.50 in.; 1933, 4.56 in.; 1934, 4.94 in.; 1935, 1.79 in.; and 1936, 1.16 in. In 1933 about 70 per cent of the rainfall listed above occurred in August and September, while in 1934 about 60 per cent occurred during the first two weeks after planting.

The irrigation water applied [3] averaged 16.22 inches per year. This was applied in four irrigations, except in 1933 when an additional application was made immediately after planting and in 1934 when because of a shortage of water only two applications could be made. While these two applications in 1934 were heavy, the plants suffered severely from July 20 to August 9, and again during the last half of September. This moisture shortage was reflected in the low yields for that year.

The soil of the experimental plots has been classified as a Tripp very fine sandy loam and is typical of the extensive areas of terraces lying north of the North Platte river. It is readily permeable to water, well drained, and productive. The reaction is alkaline, averaging about pH 7.5. The plots are one-fourth acre in size.

The following is a list of the rotations used for this study arranged in numerical order for convenient reference:

4 Potatoes
20 Sugar beets, potatoes
21 Sugar beets (manure), potatoes
24 Oats, potatoes
25 Oats (manure), potatoes
26 Corn, potatoes
27 Oats (rye), potatoes
30 Oats, sugar beets, potatoes
31 Oats (manure), sugar beets, potatoes
40 Sugar beets, alfalfa (2 years), potatoes
44 Oats, alfalfa (2 years), potatoes
60 Oats, sugar beets, alfalfa (3 years), potatoes
61 Oats (manure), sugar beets, alfalfa (3 years), potatoes
64 Sugar beets, oats, alfalfa (3 years), potatoes
71 Sugar beets (manure), sugar beets, oats, alfalfa (3 years), potatoes

All of these rotations were started in 1912, except rotations No. 64 and No. 71, which were started in 1920. Each crop in the rotation is grown each year; that is, there are as many plots for each rotation as there are years in the cycle of the rotation. The cultural practices employed have been in keeping with the better practices used in the locality, and as far as possible the same treatments have been given to all plots of the same crop. Spring plowing has been used in all potato plots except those preceded by oats, which were fall plowed. All plots in potatoes have been planted to the same variety from the same source. The Bliss Triumph variety has been used since 1920.

[2] Effective rainfall is here considered as precipitation amounting to more than 0.25 inch in 48 hours. The records were obtained from the U. S. Weather Bureau records taken at the Scottsbluff Substation.

[3] The authors are indebted to Mr. Leslie Bowen of the Bureau of Agricultural Engineering of the U. S. Department of Agriculture, stationed at the Scottsbluff Substation, for the irrigation records.

The yields [4] for the five-year period 1932-36 are presented in Table 1. The largest yields were harvested in 1933 and the lowest in 1934. The rotations of four years or more with alfalfa preceding potatoes and the shorter rotations in which manure was included produced the greatest total yield and also the greatest yield of marketable tubers. The continuous potato plot No. 4 had the lowest yield, while the other plots fell midway between these two extremes. While these yields may include the influence of diseases that reduce total yields, they do not take into account those diseases that affect the quality of the potato. These effects will be discussed with each specific disease.

TABLE 1.—*Potato yields for 1932-36, Scottsbluff rotation plots.*[1]

Plot No.	Total yields in bushels per acre						Average yield No. 1 size [2]	
	1932	1933	1934	1935	1936	5 yr. aver.	5 yrs.	4 yrs. [3]
	Bu.	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*
4	72.7	83.7	29.7	43.2	64.3	58.7	...	33.5
20	131.3	177.3	79.3	100.9	164.0	130.6	89.7	103.0
21	258.7	391.1	99.3	318.0	209.3	255.3	211.8	253.4
24	100.6	183.1	48.7	116.8	177.0	105.2	92.5	111.4
25	242.7	347.4	37.3	253.1	170.7	210.2	...	219.0
26	110.0	160.8	71.3	70.7	78.0	98.2	...	79.2
27	162.0	291.3	72.0	129.3	79.7	146.9	...	137.9
30	159.3	233.5	119.3	126.6	137.0	155.1	113.2	126.6
31	298.0	362.1	132.7	289.9	124.7	241.5	...	158.6
40	188.0	384.1	102.7	340.3	228.7	248.8	205.0	245.7
44	155.3	383.7	30.0	246.5	234.7	210.0	179.1	221.5
60	288.7	423.9	143.3	248.7	132.0	247.3	206.0	238.9
61	323.3	396.9	148.7	328.6	196.3	278.8	235.5	279.2
64	254.7	415.2	165.3	368.7	224.7	285.7	238.6	278.9
71	300.6	383.7	110.7	355.1	155.0	261.0	222.4	264.5

[1] The author is indebted to the Office of Western Irrigation Agriculture, U. S. Department of Agriculture, and Mr. Lionel Harris, Acting Superintendent of the Scottsbluff Substation, for all yield data.

[2] No. 1 size means potatoes over 1⅞ inches in diameter.

[3] Because of the low yields in 1934, records were not made of the size grades from some of the plots and for a comparison of all plots the year 1934 is omitted in this column.

The crops used in the rotations are those commonly grown in the area and the plan of the rotations is such that a study of the soil-borne diseases can be made in relation to the effect of (1) the length of the rotation, (2) manurial treatments, (3) alfalfa as green manure, and (4) the other crops in the rotation, especially the crop immediately preceding potatoes. The original plan was devised primarily for a study of the effect of these various factors and modifications of them upon the yields of the crops and the continued fertility of the soil. Because they were not originally planned for the study of disease factors, it is often impossible to separate the effect of the length of time elapsing between potato crops from changes in disease content due to the crops used in the rotation. It is possible, however, to determine the desirable and undesirable rotations

[4] For further information on the yields of these plots, the reader is referred to U. S. Dept. Agr. Tech. Buls. 483 and 512, by S. H. Hastings.

from the standpoint of both yield and disease, even though the reasons for their differences cannot be deduced with certainty.

The data in the following tables and figures are based upon a careful examination of each tuber in a 100-pound random sample selected from each plot in the field at harvest time. During the years 1929 to 1932 disease records were obtained separately for each of the size grades listed in Figure 1. The sizes listed are No. 1, over 1⅞ inches; No. 2, 1½ to 1⅞ inches; and No. 3, less than 1½ inches in diameter. Since 1932 only the No. 1-size tubers were examined, except in 1934 when the yields were low because of drouth and all sizes were used.

Inasmuch as the potato grower is primarily interested in the marketable-size potatoes, the discussion of the data in this bulletin is chiefly confined to potatoes of that size. The detailed methods used in recording the diseases will be presented with the discussion of the data.

SCAB

A record of the occurrence of scab was made by grading each tuber in the sample as having slight, moderate, or severe scab, on the basis of the amount of the surface of the tuber infected. The scab was also listed as being of common, pitted, or russet type. These scab classes were recorded separately for each of the size grades during the years 1929 to 1932 [5]. Thereafter only tubers over 1⅞ inches in diameter were used in making scab records, except in 1934 when all sizes were grouped together. In order to conserve space and for clearer presentation, the records for the first three years are not given, because the classes used for grading scab were slightly different from those used in the later years and the results were similar.

The results during the first four years of the test indicated that while the amount of scab varied with the size of the tuber, the relative effect of the rotations on scab was similar for each of the size grades. The results for one year, 1932, are used as an example in Figure 1. It is evident from Figure 1 that the percentage of healthy and slightly infected tubers was usually greater in the smaller size potatoes in all of the rotations where a large percentage of scab occurred. In the best rotations, Nos. 40 and 60, the percentage of scab was so small and there were so few small tubers that any differences due to size were not evident. This greater severity of scab on the larger-size tubers has been observed each year.

Figure 1 also illustrates the effect of the size of the tuber on the type of scab produced. The percentage of pitted scab was always least in the small-size tubers.

As regards the effects of the different rotations, the results presented in Figure 1 show that the least scab occurred in the long rotations, Nos. 40 and 60, where alfalfa preceded potatoes. The amount of scab was not so great, nor was the type of scab so severe in the continuous potato plot No. 4 as in the short rotations. The greatest amount of pitted scab occurred in rotations 20, 21, 30, and 31.

[5] The authors are indebted to Dr. H. O. Werner for the scab data for the years 1929 to 1931.

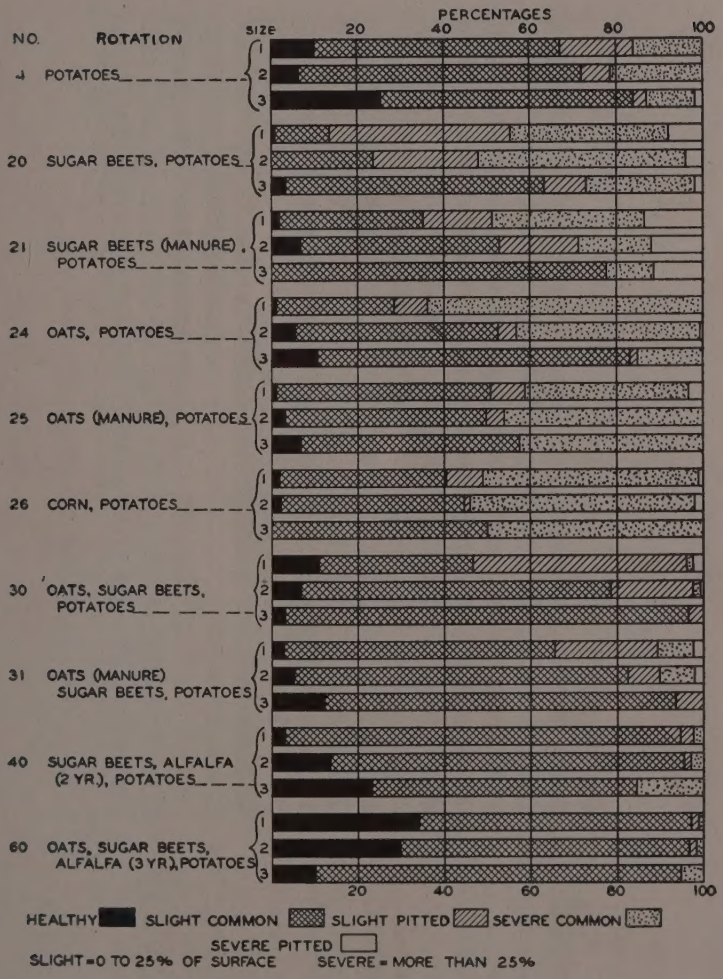

FIG. 1.—Relation of crop rotation and size of tuber to type and severity of scab in 1932.

The relatively small amount of severe scab and the almost total lack of the pitted type of scab in the plot planted continuously to potatoes is somewhat at variance with popular opinion. It has been pointed out that (Fig. 1) the percentage of pitted scab was least in the small-size tubers. The plot continuously in potatoes (No. 4) produces very few

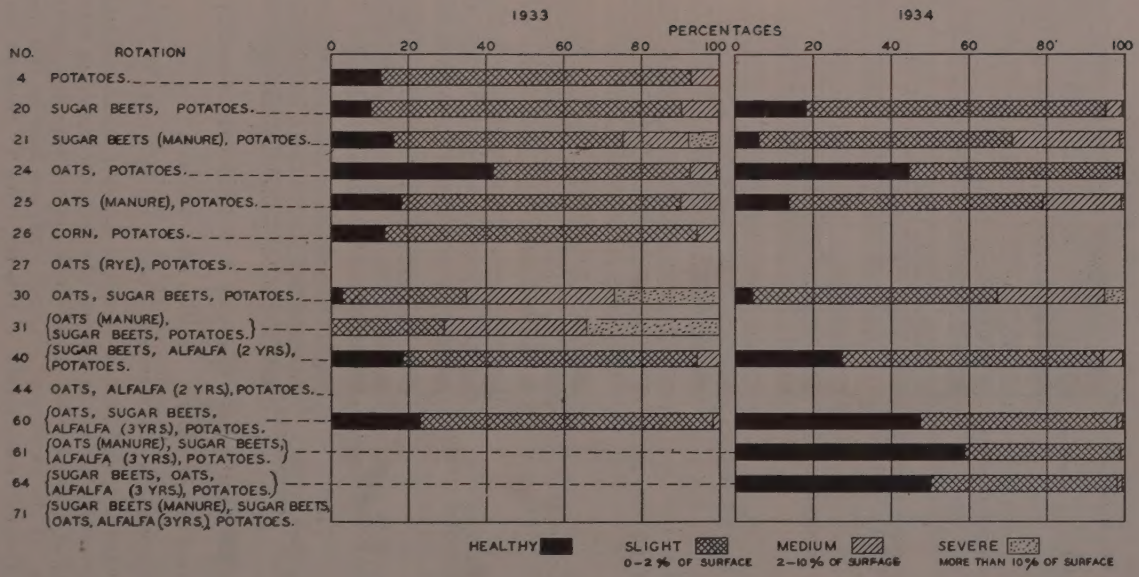

FIG. 2.—Effect of crop rotation on potato scab in 1933 and 1934.

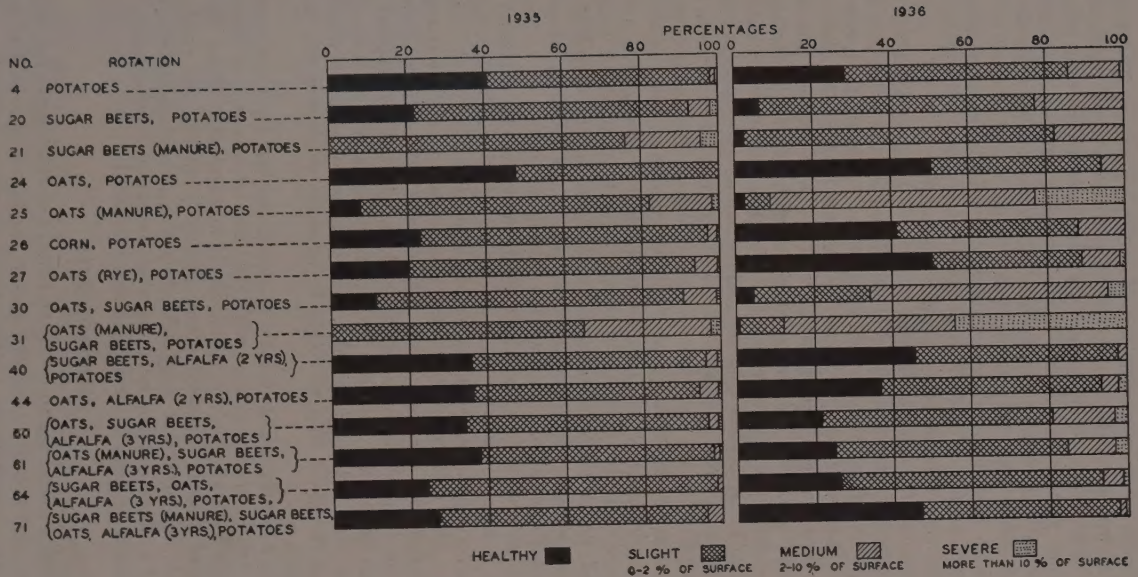

FIG. 3.—Effect of crop rotation on potato scab in 1935 and 1936.

marketable-size tubers because of lack of fertility (Table 1). The vines are usually dead by the middle of August. Examination of the tubers reveals that many scab infections are present on each tuber in the form of small, inconspicuous surface lesions and much russeting but no conspicuous or pitted types of scab lesions are present. Contrasted with this, the percentage of pitted scab has usually been found to be greater in those rotations with high fertility even though the total number of infections may be very small. It would thus appear that there is a relationship between the type of scab and tuber development.

The amount of scab occurring in the years 1933 to 1936 on No. 1-size tubers is recorded graphically in Figures 2 and 3. As previously noted the basis for classifying scab in 1932 (Fig. 1) was different from that used in the next four years (Figs. 2 and 3) and for that reason direct comparisons of percentages are impossible. The same relative differences, however, are evident. The long rotations with alfalfa preceding the potatoes produced the fewest scab culls. The two-year rotation with oats (No. 24), the same rotation with the addition of winter rye turned under preceding potatoes (No. 27), and the two-year rotation with corn (No. 26), produced about the same percentages of marketable potatoes as did the longer rotations. These two-year rotations, however, were undesirable from the standpoint of yield as shown in Table 1. The greatest amount of scab occurred in the rotations in which sugar beets preceded potatoes, Nos. 20 and 30, and these were much worse from the standpoint of scab than the plot continuously in potatoes. In the longer rotations where the sugar beets preceded alfalfa there was no increase in scab.

The use of manure in the short rotations materially increased the amount of scab as shown by the comparison of rotations 20, 24, and 30 with the corresponding rotations in which manure was added, Nos. 21, 25, and 31. This effect of manure was evident even when it was applied one year before the potatoes, as in rotation No. 31. The addition of manure in the longer rotations, Nos. 61 and 71, where it was applied four or five years before the potatoes, had no apparent effect on scab. It is possible that with a heavier soil the decomposition of manure would be retarded and the effect on scab might be apparent even after this longer period of time.

While these results might indicate that neither sugar beets nor manure should be used in short rotations with potatoes, an analysis of the yield data in Table 1 shows that this conclusion is unwarranted. Even though the amount of scab is increased when manure is applied the yields are doubled and the number of marketable tubers is greatly increased. It is clear that if a short rotation must be used the addition of manure is a desirable practice because of the great increase in yield.

RHIZOCTONIA

The records in this bulletin of the occurrence of rhizoctonia are limited to that phase of the disease exhibited by the production of sclerotia on the tubers. It was impossible to obtain records of stem lesions or sprout

injury without seriously interfering with the yield records of these permanent plots. Each individual tuber in the sample was examined for the presence of sclerotia and the severity of infection. The infected tubers were graded in three classes as follows: *slight,* aggregate sclerotia being less than two per cent of the tuber surface; *medium,* two to five per cent of the surface; and *severe,* more than five per cent. The results were recorded on a weight basis.

The relation of the size of the tuber to severity of infection was studied in 1932. There was less of the severe type of rhizoctonia in the smaller-size potatoes but there was very little difference in the percentage of healthy tubers. The relative amount and severity of infection in the different plots was much the same for each size grade and therefore in the following years the records were made only on the No. 1 size tubers.

It was evident from the same data that the plots having the highest percentage of infected tubers also had the most severe infection (number of sclerotia or area of tuber surface infected as shown by a comparison of the slight, medium, and severe classes of infection). It was therefore decided that the percentage of all infected tubers served as a good basis of comparison for the different plots and the data are used in this way in Table 2, which presents the results for the five-year period 1932 to 1936.

TABLE 2.—*Effect of crop rotation on rhizoctonia infection of potato tubers in the irrigated rotation plots at the Scottsbluff Substation, Nebraska.*

Plot No.	Crop rotation	Percentage of infected tubers [1]				
		1932	1933	1934	1935	1936
4	Potatoes	72	66	..	97	45
20	Sugar beets, potatoes	40	12	25	49	5
21	Sugar beets (manure), potatoes	10	13	13	27	3
24	Oats, potatoes	47	10	18	48	20
25	Oats (manure), potatoes	28	2	11	17	7
26	Corn, potatoes	29	7	..	51	13
27	Oats (rye), potatoes	..	..	..	34	6
30	Oats, sugar beets, potatoes	28	21	17	45	9
31	Oats (manure), sugar beets, potatoes	12	10	..	40	1
40	Sugar beets, alfalfa (2 yrs.), potatoes	10	4	3	7	0
44	Oats, alfalfa (2 yrs.), potatoes	..	..	5	8	3
60	Oats, sugar beets, alfalfa (3 yrs.), potatoes	2	1	5	13	2
61	Oats (manure), sugar beets, alfalfa (3 yrs.), potatoes	..	..	2	5	0
64	Sugar beets, oats, alfalfa (3 yrs.), potatoes	..	..	6	5	1

[1] Percentages calculated on the weight of infected tubers in a 100-lb. random sample of No. 1 size tubers.

The greatest amount of infection occurred every year in the continuous potato plot, No. 4. The least amount occurred in the four- and six-year rotations in which alfalfa preceded potatoes. There were no consistent differences betwen the two-year rotations without manure when corn, oats,

or sugar beets alternated with potatoes. There was a reduction in the percentage of infected tubers in most instances when manure was used in the two-year rotations, Nos. 21 and 25, preceding potatoes, as compared with the corresponding rotations without manure, Nos. 20 and 24. This effect of manure was also evident in a comparison of the three-year rotation 30 with 31, where manure had been applied preceding the sugar beets. The use of rye as a green manure in the two-year rotation, No. 27, with oats, materially decreased the percentage of tubers with sclerotia in the two years that records were made, as compared with its companion rotation No. 24.

The effect of manure is also shown in Figure 4, where the different classes of rhizoctonia are presented for these plots in contrast with the continuous potatoes and examples of the four- and six-year rotations. The degree of severity paralleled the percentage of infected tubers. It has often been stated that manure tends to increase the amount of rhizoctonia infection but this was not true in these plots as regards the formation of sclerotia on the tubers.

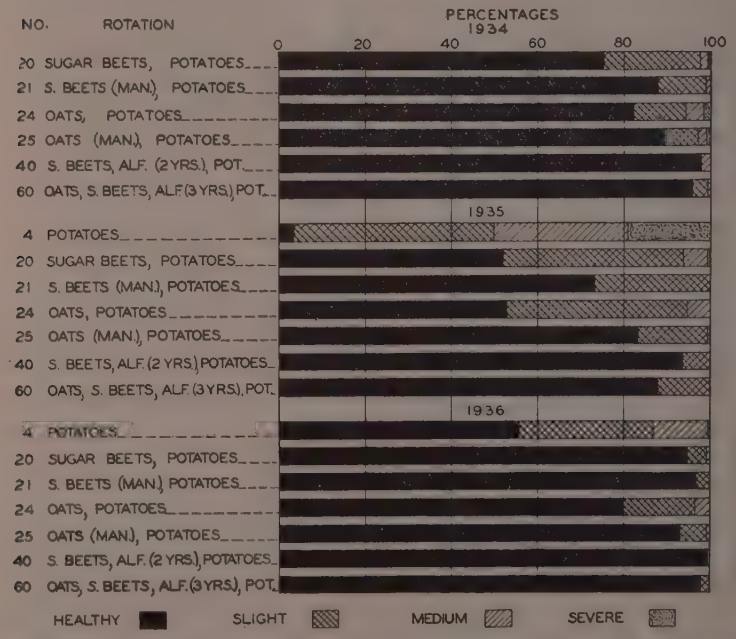

FIG. 4.—The influence of crop rotation and the application of barnyard manure on rhizoctonia infection of tubers in 1934, 1935, and 1936.

It might be argued that even though sclerotia did not form on the tubers, the percentage of stem infection might be increased. No direct evidence is available from these plots on this point but a glance at the yield records in Table 1 reveals that if this did occur it did not have any marked effect on yield, because these manured plots always had greater yields than the unmanured. There was no indication of sprout injury affecting the stand and there were no foliage symptoms indicating stem girdling. Further investigations are being undertaken to try to determine the reasons for these results with manure.

It is impossible from the available data to make direct comparisons to determine whether the time factor or the type of crop in the rotation is the cause of the smaller amount of rhizoctonia occurring in the longer rotations. It is quite obvious from Table 2 and Figure 4 that the four- and six-year rotations result in such a small amount of rhizoctonia that it is of no practical significance. In the two- and three-year rotations without manure the amount of infection was serious. Samples from additional rotation plots in which sweet clover precedes potatoes in two-, three-, and four-year rotations, have failed to yield consistent results, probably because of the shorter period of time these rotation plots have been in use. The tendency, however, has been toward a decreased amount of rhizoctonia in those plots where potatoes are preceded by sweet clover.

It is evident from the data presented that four- and six-year rotations with alfalfa preceding potatoes are desirable from the standpoint of control of rhizoctonia. If a short rotation must be used, it is advisable to use manure in the rotation. Judging from the decreased amount of infection resulting from plowing under rye in the oat and potato rotation (No. 27), it is possible that a green manure such as sweet clover might adequately control rhizoctonia in a short rotation.

FUSARIUM WILT

During the years 1932 to 1936 records were made of the number of plants in each plot showing typical symptoms of fusarium wilt. The number of readings varied but the last reading was made during the first part of September in each year. The most accurate records were made in 1934 and 1935, when all infected plants were staked, while in the other years it is possible that plants killed early in the season may have been missed in the late-season inspections. All of the plots had comparable stands, approximately 3,800 seed pieces being planted per plot.

In all of the field records an attempt was made to distinguish between wilt caused by *F. oxysporum* and that produced by infection with *F. solani* v. *eumartii*. While it is admittedly impossible to distinguish these correctly in every instance, the method of staking each infected plant and watching the development of symptoms, as was done in 1934 and 1935, reduces the error to a very low point as compared with any single examination. It is probable that a few of the plants listed as being of the *F. oxysporum* type may have been caused by the other species, but the reverse was improbable.

The records for the three years 1933 to 1935 are presented in Table 3. It can readily be seen that the great majority of infected plants do not develop symptoms until late in August or early September. The few plants showing symptoms in July and early August were mostly of the *F. oxysporum* type, while the majority of those developing symptoms later were of the *F. solani* v. *eumartii* type. The last reading for each year is the total for the year and the data show that the *F. solani* v. *eumartii* type constituted 65 to 95 per cent of all the wilt occurring in the plots.

TABLE 3.—*Time of appearance of symptoms of Fusarium oxysporum and F. solani v. eumartii in the irrigated rotation plots at the Scottsbluff Substation, Nebraska.*[1]

Date of records	F. oxysporum			F. solani v. eumartii			Total all infection	Percentage of total attributed to	
	Infected	Dead	Total	Infected	Dead	Total		F. oxysporum	F. sol. v. eumartii
	No.	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*Per cent*	*Per cent*
				1933					
July 18	17	0	17	1	0	1	18	94.4	5.6
Aug. 4	1	18	19	58	3	61	80	23.8	76.2
Aug. 17	1	18	19	133	5	138	157	12.1	87.9
Aug. 31	9	34	43	568	57	625	668	6.4	93.6
				1934					
July 25	7	4	11	0	0	0	11	100.0	0
Aug. 9	24	14	38	60	5	65	103	36.9	63.1
Aug. 27	13	42	55	983	37	1020	1075	5.1	94.9
				1935					
Aug. 3	39	1	40	3	0	3	43	93.0	7.0
Aug. 19	138	23	161	254	2	256	417	38.6	61.4
Sept. 6	612	136	748	1255	110	1365	2113	35.4	64.6

[1] These records are based on the total infection in all 15 rotation plots listed in Table 4. Each reading includes the infected plants of the previous date so that the final reading is the total for the year.

An examination of the detailed data for each of the plots failed to show any consistent differences in the two types of wilt that could be attributed to the rotation system employed. In the following discussion relating to the rotations, only the total of both types of wilt will be presented.

The severity of the disease varied from year to year but the relative positions of the different rotations as regards disease content remained fairly constant (Table 4). In general the rotations of four years or longer resulted in the least disease each year. The two-year rotations of potatoes and sugar beets resulted in less wilt than any of the other two- or three-year rotations. The two-year rotation with corn (No. 26), had the most wilt in two of the five years, that with oats manured (No. 25), in two of the years, and the one with oats and rye (No. 27) in the other year.

These three rotations were among the highest every year, the average for the five years being much higher than for any other rotation. The three-year rotations with potatoes, oats, and sugar beets (Nos. 30 and 31), had more wilt than the two-year rotations of potatoes and sugar beets but less than the ones with potatoes and oats and about the same or less than the continuous potato plot No. 4. The use of manure in rotations 21, 25, and 31 showed a slight increase in wilt over the comparable unmanured rotations when the averages for the five years are compared, but the differences were too slight or varied too much from year to year to be significant. Rotation No. 71, which had the least wilt, and rotation No. 64 have only been in use since 1920, whereas all other rotations were started in 1912.

TABLE 4.—*Number of plants affected with fusarium wilt in the one-fourth-acre irrigated rotation plots at the Scottsbluff Substation during the years 1932 to 1935.*[1]

Plot No.	Crop Rotation	Number of infected plants					
		1932	1933	1934	1935	1936	Average
4	Potatoes	30	65	73	174	342	137
20	Sugar beets, potatoes	55	39	23	78	114	62
21	Sugar beets (manure), potatoes	52	9	44	133	213	90
24	Oats, potatoes	56	117	72	106	328	136
25	Oats (manure), potatoes	160	44	106	401	305	203
26	Corn, potatoes	47	124	135	163	611	216
27	Oats (rye), potatoes	68	72	204	197	384	185
30	Oats, sugar beets, potatoes	46	30	117	159	184	107
31	Oats (manure), sugar beets, potatoes	16	53	152	145	202	114
40	Sugar beets, alfalfa (2 yrs.), potatoes	53	9	36	73	128	60
44	Oats, alfalfa (2 yrs.), potatoes	26	19	25	165	107	68
60	Oats, sugar beets, alfalfa (3 yrs.), potatoes	37	24	39	104	172	75
61	Oats (manure), sugar beets, alfalfa (3 yrs.), potatoes	20	19	20	80	107	49
64	Sugar beets, oats, alfalfa (3 yrs.), potatoes	19	26	8	74	123	50
71	Sugar beets (manure), sugar beets, oats, alfalfa (3 yrs.), potatoes	..	18	21	61	48	37

[1] The approximate number of plants per plot was 3800. Direct comparisons should not be made between different years except in 1934 and 1935 when all infected plants were staked throughout the season. In 1932 the infected plants were recorded on Sept. 1; in 1933 they were recorded on four dates, July 18, Aug. 4, 17, and 31; and in 1936, on Aug. 17 and Sept. 7.

All tubers in the random samples were cut across the stem end and examined for internal vascular discoloration. The amount of infection was determined for each of the size grades in 1932 but the differences were found not to be significant and during the next four years only the No. 1 size tubers were examined, except in 1934 when all sizes were used.

The depth and type of vascular discoloration were noted. The affected tubers were divided into three classes: (1) healthy, (2) slight infection, in which the discoloration extended less than one-half inch into the tuber, and (3) severe, in which the discoloration was deeper than one-half inch or where stem-end rot was discernible externally. The results for 1936

are presented graphically in Figure 5. It can be noted in Figure 5 that the severity of infection in the individual tubers closely paralleled the percentage of tubers infected in the samples from the various rotations. This was evident for every one of the five years. Because of this and the additional fact that there is always a considerable chance of error in making readings of very slight discolorations, the data in Table 5 for all five years are based on the severe infection only. This is approximately the same as the basis for determining the amount of infection in commercial grades of both seed and table potatoes in Nebraska.

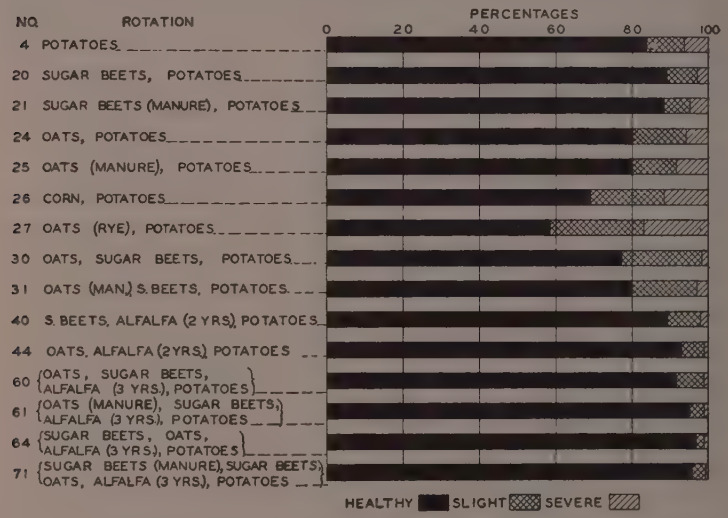

FIG. 5.—Fusarium stem-end rot and vascular discoloration as influenced by crop rotation and size of tubers in 1936.

In general the data obtained in the bin check very well with those obtained by an examination of the plants in the field. The longer rotations with alfalfa preceding potatoes are markedly superior to the other plots as regards the low percentage of infected tubers. The two-year rotations of oats or corn with potatoes show the highest percentages of disease, as they did in the field. There was no consistent difference, however, between the two-year rotation with sugar beets and the three-year rotation with sugar beets and oats. The two-year rotations with sugar beets resulted in less disease than the two-year rotations with oats, just as they did in the field readings. The continuous potato plot resulted in a high percentage of infected tubers.

It should be remembered in comparing the field and bin records that many plants listed as infected in the field may have died before tubers were produced, while other plants may have become infected so late in the

season that they were not detected at the last reading. While the data in Table 4 are given as actual counts, the percentages if figured on 90 to 100 per cent stands check very well with the bin records on tuber stem-end rot and severe internal discoloration.

It can be concluded from the data presented on fusarium wilt that the long rotations with alfalfa preceding potatoes are desirable. Short rotations with corn preceding potatoes should be avoided, since the percentage of fusarium wilt was about the same as resulted from the continuous culture of potatoes. If a short rotation must be used it is possible that sweet clover might result in less wilt than would the grain crops.

TABLE 5.—*Effect of crop rotation on fusarium wilt as indicated by internal discoloration or stem-end rot of tubers in the irrigated rotation plots at the Scottsbluff Substation, Nebraska.*

Plot No.	Crop Rotation	Percentage of infected tubers [1]				
		1932	1933	1934	1935	1936
4	Potatoes	9.0	5.8	..	4.9	6.4
20	Sugar beets, potatoes	3.9	0.9	2.5	0.4	4.1
21	Sugar beets (manure), potatoes	1.1	0.9	0.2	2.6	5.0
24	Oats, potatoes	6.6	3.1	0.4	2.4	5.9
25	Oats (manure), potatoes	3.1	2.1	1.9	3.9	9.1
26	Corn, potatoes	6.2	10.7	..	2.4	11.8
27	Oats (rye), potatoes	..	..	..	3.5	17.2
30	Oats, sugar beets, potatoes	7.6	0.5	1.0	2.7	2.7
31	Oats (manure), sugar beets, potatoes	1.3	1.4	..	1.9	4.0
40	Sugar beets, alfalfa (2 yrs.), potatoes	3.0	0.0	1.6	0.4	2.4
44	Oats, alfalfa (2 yrs.), potatoes	..	..	..	1.7	1.3
60	Oats, sugar beets, alfalfa (3 yrs.), potatoes	3.5	0.3	0.2	0.0	1.2
61	Oats (manure), sugar beets, alfalfa (3 yrs.), potatoes	..	..	0.2	0.0	0.8
64	Sugar beets, oats, alfalfa (3 yrs.), potatoes	..	..	0.0	0.0	0.8
71	Sugar beets (manure), sugar beets, oats, alfalfa (3 yrs.), potatoes	..	..	..	0.7	0.4

[1] Percentages are based on weight of No. 1 size tubers except in 1934 when all sizes were used. Tubers with stem-end rot or vascular discoloration extending more than one-half inch into the tuber were classed as infected.

CONCLUSIONS

It has been shown in the preceding data that both the length of the rotation and the crops used in the sequence affected the amounts of scab, rhizoctonia, and fusarium wilt arising from soil infection. The effect of the length of the rotation was much the same with all three diseases, particularly when there was an interval of four years or more between potato crops. The effect of some of the crop sequences and cultural practices varied with the different diseases, but the rotations resulting in the least infection were the same for all three diseases.

Fortunately, the desirable rotations from the disease standpoint are also the best ones as regards yields. It has been shown by Coons and Kotila [6]

[6] G. H. Coons and J. E. Kotila. Influence of Preceding Crops on Damping Off of Sugar Beets. Phytopath. (Abst.) 25:13, 1935.

that when sugar beets follow alfalfa there is much more "damping-off" of beet seedlings than when they follow corn or small grain. It has also been pointed out by Harris [7] and others that the beneficial effect of alfalfa is not as great on the yield of sugar beets as on potatoes, while the reverse is true of manure. In this bulletin it has been shown that the four- and six-year rotations with alfalfa preceding potatoes result in less disease in the potatoes. It is therefore quite obvious that the rotations containing both sugar beets and potatoes as cash crops, should have the soil-building legume alfalfa preceding the potato crop, and the grain crops, if in the rotation, should precede the sugar beets.

In the short rotations the addition of manure increased the amount of scab but also decreased the amount of rhizoctonia on the tubers and doubled the yield. Applications of barnyard manure are therefore advisable if a short rotation must be used. It is possible that short rotations with sweet clover might have the same beneficial effect on the disease content as does the alfalfa in the longer rotations. Data were not available in this test to decide the point but such rotations might be found very advantageous, particularly if the sweet clover is desired for pasturage.

The least desirable rotations were the corn and potato rotation and the continuous culture of potatoes, as regards both disease and yield.

There was no evidence during the five to seven years during which records were made that there was a cumulative increase in these soil-borne diseases. The plots have been under these crop sequences since 1912 and it was considered that the effect of the crop sequences was sufficiently fixed.

The results presented in this bulletin were obtained under a certain set of conditions that have been described in some detail. The application of the results under other soil and climatic conditions should be made with some reservations. A great deal of careful research will be necessary before we can accurately determine the underlying principles and apply the knowledge to other environmental conditions.

[7] Lionel Harris, Crop Rotation Work at the Scottsbluff Field Station. Ann. Rpt. Nebr. Potato Improv. Assoc. for 1936-37, pp. 5-12, 1937.